CLAIMS

We claim:

1. A radiolocation method in a wireless network comprising:

determining the relative locations of a set of wireless stations of the wireless network, each station including a local clock, each station further including a transmitter, a receiver, an analog-to-digital converter to form samples of received signals, and a buffer subsystem coupled to the analog-to-digital converter, said determining the relative locations including:

each of the set of stations at least once transmitting a packet to be received by each other station, the transmitting in a round robin manner one station after the other;

each of the stations receiving the packets transmitted by each of the other stations; and

at each receiving station,

sampling the received signal corresponding to a received packet at a rate according to an ADC clock;

capturing samples in a memory;

timestamping the captured samples according to a local timestamping clock related to the station's local clock; and

sending the timestamped captured samples to a processing entity,

such that the processing entity can determine the times of arrival of each packet at each station, and from the determined times of arrival, mutually calibrate the stations' local clocks, and further determine the relative positions of the stations by determining the time-of-flight between the stations of the radio signals corresponding to the transmitted packets.

2. A method as recited in claim 1, wherein mutually calibrating the stations' local clocks determines the relationship of each station's local clock to a global time measure.

3. A method as recited in claim 1, wherein each of the transmitting stations further sends to the processing entity a transmit timestamp indicating the time of transmitting, according to its local timestamping clock related to the station's local clock.

4. A method as recited in claim 3, wherein the number of round robin transmissions is sufficient to mutually calibrate the stations' local timestamping clocks under the assumption that any drift in the timestamping clock of each station depends on one or more unknown parameters.

5. A method as recited in claim 4, wherein the determining at the processing entity includes:

assuming a relationship between the local time and a global time common to the stations of the set, the relationship defined by the sets of one or more parameters, and determining the sets of parameters from the local times of arrival of the received packets.

6. A method as recited in claim 3, wherein each receiving station's ADC clock is related to the station's local clock, such that the timestamping clock is related to the ADC clock.

7. A method as recited in claim 6, wherein the wireless network conforms to at least one variation of the IEEE 802.11 standard, and wherein the stations are access points (APs) coupled to the processing entity.

8. A method as recited in claim 7, wherein the processing entity is one of the APs.

9. A method as recited in claim 7, wherein the processing entity is a device coupled by a network to each of the APs.

10. A method as recited in claim 9, wherein the sending the timestamped captured samples uses one or more Ethernet packets.

11. A method as recited in claim 6, further comprising:

determining the location of an additional station, including:

at least some of the stations receiving a packet transmitted by the additional station; and

at each receiving station,

sampling the received signal corresponding to a received packet at a rate according to the station's ADC clock related to the local clock;

capturing samples in the memory;

timestamping the captured samples according to the station's local clock related to the ADC clock; and

sending the timestamped captured samples to a processing entity;

such that the processing entity can determine the times of arrival of the packet at each receiving station, and from the determined times of arrival and the relationship between each receiving station's local clock, determine the relative positions of the additional station.

12. A radiolocation method in a wireless network comprising:

receiving transmit timestamps from a set of wireless stations of the wireless network, each station transmitting at least once, each station including a local clock, a transmitter, a receiver, and a local timestamping clock related to the station's local clock, each transmit timestamp using the local timestamping clock and corresponding to when each of the set of stations transmitted a packet to be received by each other station;

receiving sets of timestamped captured samples sent from each station that receives one of the transmitted packets, each receiving station further including an analog-to-digital converter to form samples of received signals, and a memory coupled to the analog-to-digital converter, each receiving station sampling the received signal corresponding to a received packet at a rate according to an ADC clock, capturing samples in the memory, and timestamping the captured samples according to a local timestamping clock related to the station's local clock, and sending a set of timestamped captured samples;

from the received sets of timestamped captured samples, determining the times of arrival of each packet at each station; and

from the determined times of arrival and the received transmit timestamps, determining the relative positions of the stations by determining the time-of-flight between the stations of the radio signals corresponding to the transmitted packets.

13. A method as recited in claim 12, wherein the transmitting by the stations is in a round robin manner one station after the other, and wherein the number of round robin transmissions is sufficient to mutually calibrate the stations' local timestamping clocks under the assumption that any drift in the timestamping clock of each station depends on one or more unknown parameters.

14. A method as recited in claim 12, wherein determining the times of arrival of each packet includes for each set of captured samples:

forming a set of samples of a reference signal that corresponds to at least part of the packet that was sent to the station; and

correlating the reference signal samples with the captured samples to obtain a correlated result.

15. A method as recited in claim 14, wherein determining the times of arrival of each packet at each station further includes:

deconvolving the correlated result with one or both of a model of the propagation channel and a measure of the autocorrelation of the reference signal, the deconvolving being at least around the expected location in time of the first peak of the results of correlating; and

determining the location of the first peak of the results of the deconvolving as an indication of the time of arrival.

16. A method as recited in claim 14, wherein the channel model is a set of impulses of different amplitudes, being a model of multipath.

17. A method as recited in claim 14, wherein the deconvolving uses the method known as CLEAN or a variant thereof.

18. A method as recited in claim 14, wherein the deconvolving uses maximum entropy method (MEM) or a variant thereof.

19. A method as recited in claim 14, wherein the deconvolving uses a maximum likelihood method.

20. A method as recited in claim 14, wherein the packet that was sent to the station conforms to one of the OFDM variants of the IEEE 802.11 standard, and wherein forming a set of samples of the reference signal includes demodulating and decoding the captured samples, and re-modulating the decoded samples to form the set of samples of the reference signal from at least part of the payload section of the decoded packet.

21. A method as recited in claim 14, wherein the packet that was sent to the station conforms the IEEE 802.11b standard, and wherein forming a set of samples of the reference signal uses the preamble part of an IEEE 802.11b packet.

22. A method of radiolocation using time difference of arrival, comprising:

determining the times of arrival of wireless transmissions from timestamped sets of samples of signals received at a plurality of stations of a wireless network and sent by the stations to a processing entity.

23. A method as recited in claim 22, further comprising;

determining time differences of arrival from the determined times of arrival and from transmit timestamps sent by transmitting stations to the processing entity.

24. A method as recited in claim 22, wherein determining the times of arrival includes for each set of captured samples:

correlating the timestamped sets of samples with a reference signal that represents at least part of the signal expected to have been received at each station; and

deconvolving the timestamped sets of samples of signals.

25. A method comprising:

receiving transmit timestamps from a set of wireless stations of a wireless network, each station transmitting at least once, each transmit timestamp using a local timestamping clock to indicate when the stations transmitted a packet;

receiving sets of timestamped captured samples from each station that receives one of the transmitted packets, each set of timestamped captured samples being of a signal received at the respective station;

from the received sets of timestamped captured samples, determining the times of arrival of each packet at each station; and

from the determined times of arrival and the received transmit timestamps, determining the relative positions of the stations.

26. A method as recited in claim 25, wherein the transmitting by the stations is in a round robin manner one station after the other, and wherein the number of round robin transmissions is sufficient to mutually calibrate the stations' local timestamping clocks under the assumption that any drift in the timestamping clock of each station depends on one or more unknown parameters.

27. A method as recited in claim 25, wherein determining the times of arrival of each packet includes for each set of captured samples:

correlating the captured samples with a reference signal to obtain a correlated result, the reference signal corresponding to at least part of the signal that was transmitted;

correlating the reference signal samples with the captured samples to obtain a correlated result;

deconvolving the correlated result; and

determining the location of the first peak of the results of the deconvolving as an indication of the time of arrival.

28. A method as recited in claim 27, wherein the deconvolving uses the method known as CLEAN or a variant thereof.

29. A carrier medium carrying one or more code segments to instruct a processor of a processing system to implement a method, the method comprising:

receiving transmit timestamps from a set of wireless stations of a wireless network, each station transmitting at least once, each transmit timestamp using a local timestamping clock to indicate when the stations transmitted a packet;

receiving sets of timestamped captured samples from each station that receives one of the transmitted packets, each set of timestamped captured samples being of a signal received at the respective station;

from the received sets of timestamped captured samples, determining the times of arrival of each packet at each station; and

from the determined times of arrival and the received transmit timestamps, determining the relative positions of the stations.

30. A carrier medium as recited in claim 29, wherein determining the times of arrival includes for each set of captured samples:

correlating the captured samples with a reference signal to obtain a correlated result, the reference signal corresponding to at least part of the signal that was transmitted;

correlating the reference signal samples with the captured samples to obtain a correlated result;

deconvolving the correlated result; and

determining the location of the first peak of the results of the deconvolving as an indication of the time of arrival.

31. A carrier medium as recited in claim 30, wherein the deconvolving uses the method known as CLEAN or a variant thereof.

32. An apparatus comprising:

means for receiving transmit timestamps from a set of wireless stations of a wireless network, each station transmitting at least once, each transmit timestamp using a local timestamping clock to indicate when the stations transmitted a packet;

means for receiving sets of timestamped captured samples from each station that receives one of the transmitted packets, each set of timestamped captured samples being of a signal received at the respective station;

means for determining the times of arrival of each packet at each station from the received sets of timestamped captured samples; and

means for determining the relative positions of the stations from the determined times of arrival and the received transmit timestamps.

33. An apparatus as recited in claim 32, wherein the means for determining the times of arrival includes:

means for correlating the captured samples with a reference signal to obtain a correlated result, the reference signal corresponding to at least part of the signal that was transmitted;

means for deconvolving the correlated result; and

means determining the location of the first peak of the results of the deconvolving as an indication of the time of arrival.

34. A carrier medium as recited in claim 33, wherein the deconvolving uses the method known as CLEAN or a variant thereof.

35. An apparatus in a station of a wireless network, the apparatus including:

a local clock;

a transmitter;

a receiver;

an analog-to-digital converter to form samples of received signals, the sampling at a rate according to an ADC clock related to the local clock;

a buffer subsystem coupled to the analog-to-digital converter;

a timestamping clock coupled to the local clock; and

a trigger circuit coupled to the buffer subsystem, to the timestamping clock, and to the transmitter to indicate when the station transmits a packet such that the station can send a transmit timestamp to a processing entity, the transmit timestamp indicating when the packet was transmitted, the trigger circuit also coupled to the receiver such that the station is able to capturing samples of a received signal in the buffer subsystem, timestamp the captured samples; and send the timestamped captured samples to the processing entity,

such that the processing entity can determine the times of arrival of each packet at each station, and from the determined times of arrival, further determine the relative positions of the stations by determining the time-of-flight between the stations of the radio signals corresponding to the transmitted packets.

36. An apparatus as recited in claim 35, wherein the ADC clock is related to the local clock, such that the timestamping clock is related to the ADC clock.

37. A method as recited in claim 36, wherein the ADC clock runs at an integer multiple of the frequency of the timestamping clock, said integer being at least one.

38. An apparatus as recited in claim 36, wherein the wireless network conforms to at least one variation of the IEEE 802.11 standard, and wherein the station is an access point (AP) coupled to the processing entity.

39. An apparatus as recited in claim 38, wherein the processing entity is a device coupled by a network to the AP.

40. An apparatus as recited in claim 35, wherein the sending to the processing entity uses Ethernet packets.

41. An apparatus for inclusion in a station of a wireless network, the apparatus comprising a buffer subsystem and a timestamping subsystem, such that the station can capture and timestamp a set of samples of a received signal, and send the captured

timestamped samples to a processing entity for time difference of arrival location determination.